α-Particle Spectroscopy with Si

Purpose: Learn about α-particle spectroscopy techniques using solid-state Si detectors. Understand α-particle decays and how levels are how daughter products can also be a source of α particles.

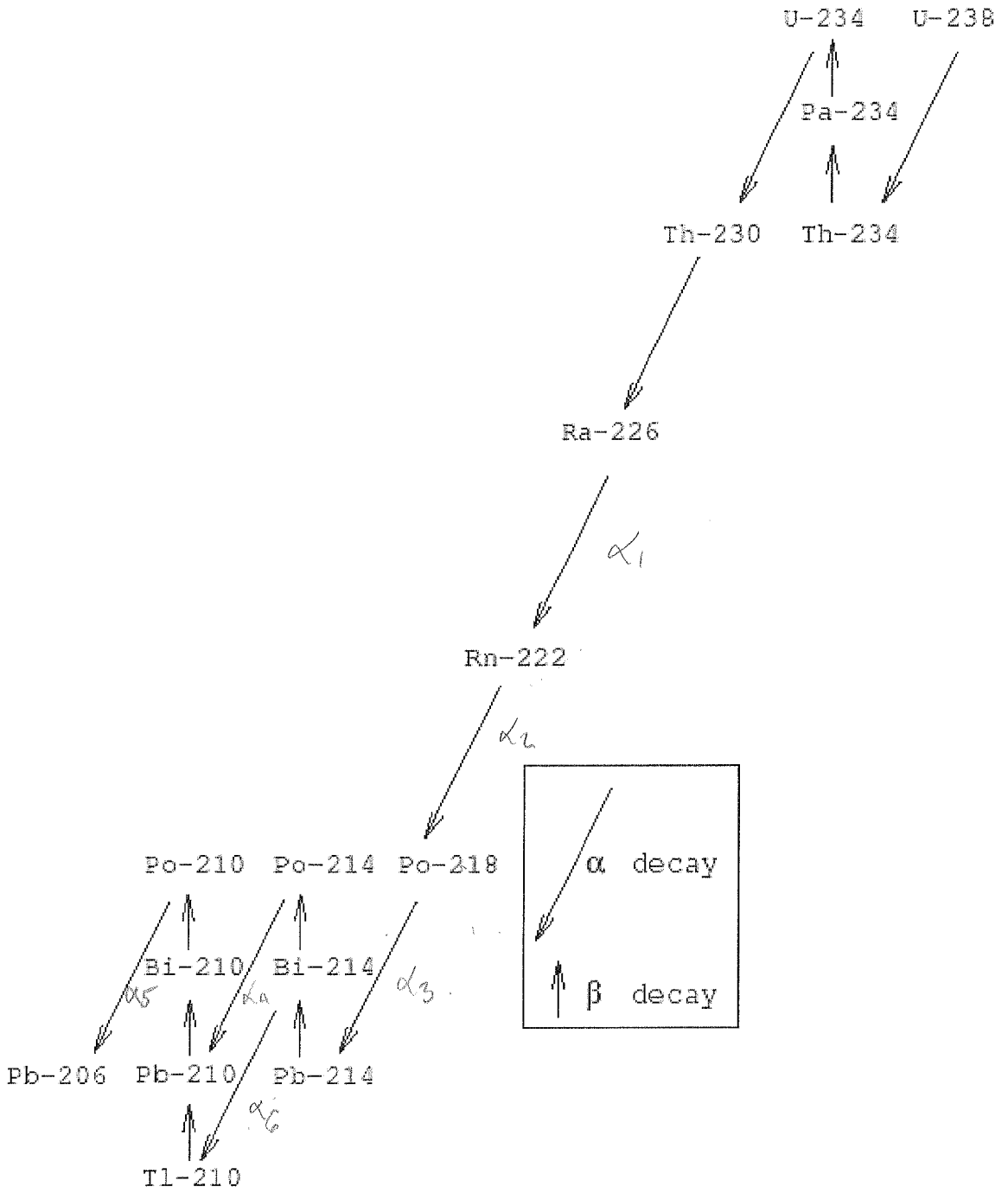
Overview: We will be studying α particles from a source which was originally pure ^{226}Ra.

Goals:

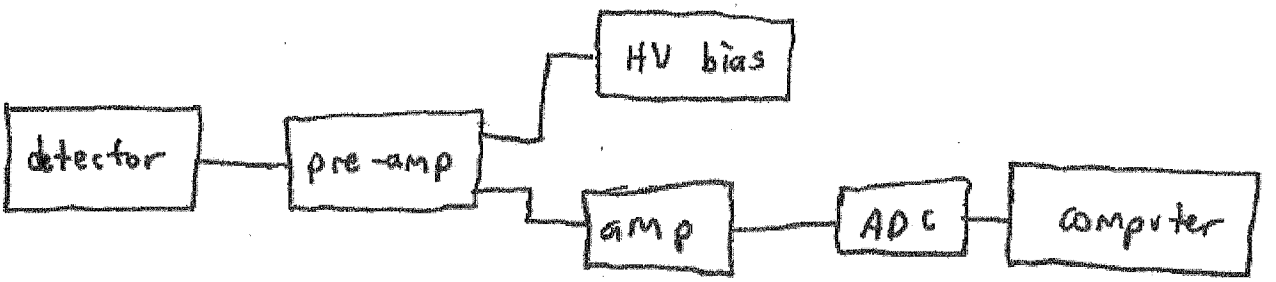
- Understand the α-particle decay of ^{226}Ra and its daughter products.
- Understand the logic of the electronics used, the purpose of each module employed, and the setup of timing, gates, gains.
- Understand the features of the energy spectrum.
- Perform an energy calibration for the detector using the energies of known peaks.
- Determine the energy resolution for the detector.
- Determine the activity of the source.
- Identify the daughter products from their Q-values and intensity.
- Determine the age of source, relative to the time when it was pure ^{226}Ra.
- Keep a detailed logbook of all relevant details.
- Access the literature to determine the expected properties of each isotope.
- Prepared a detailed formal laboratory report on these investigations.

For the first day in the lab:

- Read all of the background material beforehand.
- Understand the list of goals.
- Begin to familiarize yourself with the experimental setup.
- Try to understand each part of the system.
- Become familiar with the the oscilloscope and use it to look at the linear and logical signals and various points in the setup.
- Learn about how the digitized signals are stored in the computer.


U-234
U-238
Pa-234
Th-230
Th-234
Ra-226
α1
Rn-222
α2
Po-210
Po-214
Po-218
α decay
β decay
Bi-210
Bi-214
α5
α4
α3
Pb-206
Pb-210
Pb-214
α6
Tl-210

Electronics Setup



- The chamber must be evacuated before starting the measurements. Do not leave the high-voltage bias on when either pumping out or venting the chamber. Any ideas why?
- The bias voltage for our detector BA-024-300-500 is 250 V.
- The detector is connected to a pre-amplifier by a single coaxial cable.
- The high-voltage bias for the detector is supplied to the preamp.
- The pre-amp output is sent to an amplifier.
- The amplifier output is sent to an ADC.
- The digital data from the ADC is stored in the computer.

Your Technical Report Should Include:

- A plot of the α spectrum.
- A table of Energies and Channels for the peaks observed.
- A plot of Energy versus Channel for the peaks observed.
- Identification of the peaks observed.
- Determine the energy calibration of the detection system.
- Determine the energy resolution of the detection system.
- Determine the number of ^{226}Ra atoms present in the source.
- Determine the age of source, relative to the time when it was pure ^{226}Ra.

This lab manual (such as it is) was written by Carl Brune, starting in Spring 2005.

Appendix 1: Decay of ^{226}Ra

88-Ra-226 Radium-226
Half-life: 1600 years
Mode of decay: alpha into Rn-222
Decay energy: 4.871 MeV
Subsequently γ radiation of Rn-222 at 186 keV possible

86-Rn-222 Radon-222, noble gas
Half-life: 3.8235 days
Mode of decay: alpha into Po-218
Decay energy: 5.590 MeV

84-Po-218 Polonium-218 (Historically Po-218 is also called radium A)
Half-life: 3.10 minutes
Mode of decay: alpha into Pb-214
Probability: 99.98 %
Decay energy: 6.115 MeV
Mode of decay: beta into At-218
Probability: 0.02 %
Decay energy: 0.265 MeV

85-At-218 Astatine-218
Half-life: 1.5 seconds
Mode of decay: alpha into Bi-214
Probability: 99.90 %
Decay energy: 6.874 MeV
Mode of decay: beta into Rn-218
Probability: 0.1 %
Decay energy: 2.883 MeV

86-Rn-218 Radon-218
Half-life: 35 milliseconds
Mode of decay: alpha into Po-214
Decay energy: 7.263 MeV

82-Pb-214 Lead-214 (Historically Pb-214 is also called radium B)
Half-life: 26.8 minutes
Mode of decay: beta into Bi-214
Decay energy: 1.024 MeV
Subsequently γ radiation of Bi-214 at 352 keV, 295 keV, 242 keV, 53 keV possible

83-Bi-214 Bismuth-214 (Historically Bi-214 is also called radium C)
Half-life: 19.9 minutes
Mode of decay: beta into Po-214
Probability: 99.98 %

Decay energy: 3.272 MeV
Subsequently γ radiation of Po-214 at 609 keV possible
Mode of decay: alpha into Tl-210
Probability: 0.02 %
Decay energy: 5.617 MeV

84-Po-214 Polonium-214 (Historically Po-214 is also called radium C')
Half-life: 164.3 ms
Mode of decay: alpha into Pb-210
Decay energy: 7.833 MeV

81-Tl-210 Thallium-210 (Historically Tl-210 is also called radium C")
Half-life: 1.3 Minutes
Mode of decay: beta into Pb-210
Decay energy: 5.484 MeV

82-Pb-210 Lead-210 (Historically Pb-210 is also called radium D)
Half-life: 22.3 years
Mode of decay: beta into Bi-210
Decay energy: 0.064 MeV
Mode of decay: alpha into Hg-206
Probability: 1.9E-6 %
Decay energy: 3.792 MeV

83-Bi-210 Bismuth-210 (Historically Bi-210 is also called radium E)
Half-life: 5.013 days
Mode of decay: beta into Po-210
Decay energy: 1.163 MeV
Mode of decay: alpha into Tl-206
Probability: 0.00013 %
Decay energy: 5.037 MeV

84-Po-210 Polonium-210 (Historically Po-210 is also called radium F)
Half-life: 138.376 days
Mode of decay: alpha into Pb-206
Decay energy: 5.407 MeV

82-Pb-206 Lead-206 (Historically Pb-206 is also called Radium G)
Pb-206 is the final product of the U-238 radioactive series. It is stable. This lead is dead!

The entries are taken from the NUDAT database, see:

R.R.Kinsey, et al.,The NUDAT/PCNUDAT Program for Nuclear Data, paper submitted to the 9th International Symposium of Capture Gamma-ray Spectroscopy and Related Topics, Budapest, Hungary, October 1996. Data extracted from NUDAT database (Dec.18, 1997).

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Some Remarks on Determining the "age" of a ^{226}Ra Source

Assuming that one starts with pure ^{226}Ra, it is possible to determine its "age" (defined here to be the time since it started life in a pure state) by observing the decays of its daughter products. First note that all the decay half-lives are very short (less than one week), except for two: the initial ^{226}Ra decay ($t_{1/2} = 1600$ years) and the the ^{210}Pb decay ($t_{1/2} = 22.3$ years).

The number of ^{226}Ra atoms N_A present in the source is a function of time t and is described by

$$N_A = N_0 \exp(-t/\tau_A), \tag{1}$$

where $N_0 = N_A(0)$ and τ_A is the mean lifetime of ^{226}Ra given by $t_{1/2}/\ln 2$. The decay rate of ^{226}Ra is given by

$$-\frac{dN_A}{dt} = N_A/\tau_A. \tag{2}$$

I will assume $t = 0$ when the source was made. Note that $\frac{dN_A}{dt}$ is a quantity that you can measure in the laboratory and can be used to determine N_A.

Once the source is several weeks old, an equilibrium is established. Consider for example ^{222}Rn. In equilibrium, this isotope is produced at essentially the same rate as which is it decays – this must be the case because every ^{222}Rn which is created decays shortly thereafter. This same argument can be applied to all of the other isotopes in the decay chain which have short half-lives (i.e. less than one week). Unfortunately, these decays don't tell us anything about the age of the source.

For ^{210}Pb and ^{206}Pb we have to be a little bit more careful. Once the source is several weeks old, ^{210}Pb is produced at the same rate as ^{226}Ra decays. However, ^{210}Pb decays with a 22.3-year half-life. We can describe the number of ^{210}Pb atoms N_B as a function of time via:

$$\frac{dN_B}{dt} = -\frac{dN_A}{dt} - \frac{N_B}{\tau_B} \tag{3}$$

$$= \frac{N_0}{\tau_A}\exp(-t/\tau_A) - \frac{N_B}{\tau_B}. \tag{4}$$

The first term in this equation describes the creation of N_B by the decays of parent nuclei and the second term describes the decay of N_B due to its own half-life (τ_B is the mean lifetime of ^{210}Pb).

This is a differential equation. It can be solved by "guessing" the answer:

$$N_B = A\exp(-t/\tau_A) + B\exp(-t/\tau_B), \tag{5}$$

Where A and B are arbitrary constants. If we start with a pure ^{226}Ra source that means we have zero ^{210}Pb initially so we have $N_B(t = 0) = 0$, i.e. $A = -B$. We can determine A by substituting in Eq. (4); the final result is:

$$N_B = \frac{N_0}{\tau_A/\tau_B - 1}\left[\exp(-t/\tau_A) - \exp(-t/\tau_B)\right]. \tag{6}$$

The quantity N_B *does* tell us something about the age of the source. Unfortunately neither N_B or its decay rate can be measured directly with our setup (^{210}Pb decays by β emission).

We can apply the equilibrium argument to decays following ^{210}Pb. In particular, the decay rate of ^{210}Po is equal to the decay rate of ^{210}Pb once the source is several weeks old. The nucleus ^{210}Po decays by α emission – something which we can measure. In addition the ^{210}Po decay rate is just given by $\frac{N_B}{\tau_B}$ – something we can calculate from Eq. (6)! The comparison can be used to determine t – the age of the source.

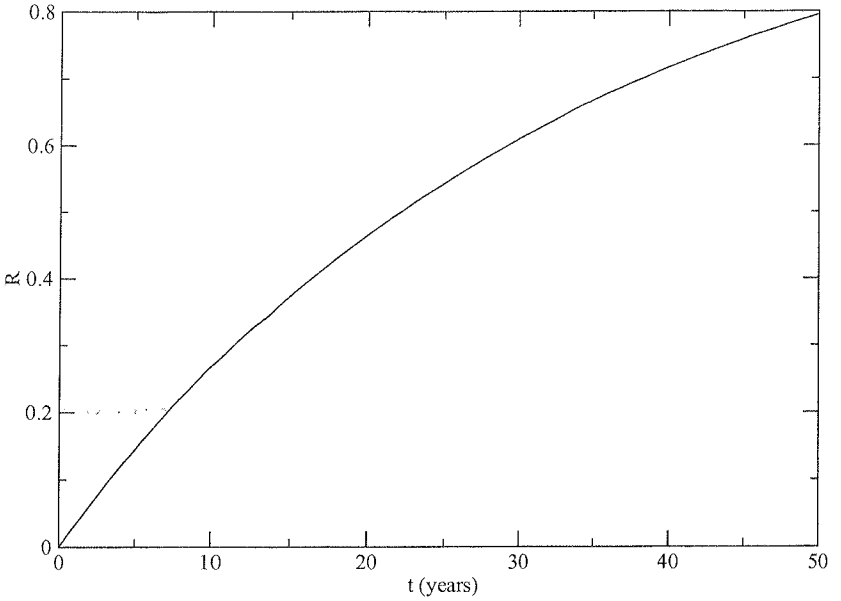

Figure 1: The ratio R as a function of the age t.

May 2007 Addenda:

Here is some more of the algebra you need to use. The decay rates of ^{226}Ra and ^{210}Pb are given by

$$\frac{N_A}{\tau_A} = \frac{N_0}{\tau_A}\exp(-t/\tau_A) \quad \text{and} \tag{7}$$

$$\frac{N_B}{\tau_B} = \frac{N_0}{\tau_A - \tau_B}\left[\exp(-t/\tau_A) - \exp(-t/\tau_B)\right]. \tag{8}$$

There is a subtle point here: the "decay rate" and and "rate of change" are not the same thing for ^{210}Pb since the rate of change also includes production. Taking the ratio, one obtains

$$R \equiv \frac{N_B\tau_A}{N_A\tau_B} = \frac{\tau_A}{\tau_A - \tau_B}\left[1 - \exp(-t/\tau_B + t/\tau_A)\right]. \tag{9}$$

The ratio R as a function of the age t is shown in Fig 1. Note also that the ratio R is also equal to the measured ratio of ^{210}Po decay αs to ^{226}Ra decay αs. Equation (9) can then be inverted to find the age t:

$$t = -\frac{\tau_A\tau_B}{\tau_A - \tau_B}\ln\left(1 - R\frac{\tau_A - \tau_B}{\tau_A}\right). \tag{10}$$

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CERTIFICATE OF CALIBRATION
ALPHA STANDARD SOURCE

Radionuclide:	Ra-226	**Customer:**	OHIO UNIVERSITY---PAYABLES
Half-life:	1600 ± 7 years	**P.O. No.:**	OU 10929
Catalog No.:	AF-226-A1	**Reference Date:**	1-Sep-06 12:00 PST
Source No.:	1198-84	**Contained Radioactivity: (Ra-226 only)**	0.08827 µCi 3.266 kBq

Physical Description:

A.	Capsule type:	A-1
B.	Nature of active deposit:	Electrodeposited and diffusion bonded oxide
C.	Active diameter/volume:	5 mm
D.	Backing:	Platinum clad nickel
E.	Cover:	Approximately 50 µg Au/cm²

CAUTION!
DELICATE SURFACE
DO NOT WIPE
ACTIVE AREA

Radioimpurities:

None detected (daughters not in equilibrium)

Method of Calibration:

This source was assayed using an alpha spectrometry surface barrier detector against a standard of similar isotopic composition and geometric configuration.

Uncertainty of Measurement:

A.	Type A (random) uncertainty:	± 0.7 %
B.	Type B (systematic) uncertainty:	± 3.0 %
C.	Uncertainty in aliquot weighing:	± 0.0 %
D.	Total uncertainty at the 99% confidence level:	± 3.1 %

Notes:

- See reverse side for leak test(s) performed on this source.
- IPL participates in a NIST measurement assurance program to establish and maintain implicit traceability for a number of nuclides, based on the blind assay (and later NIST certification) of Standard Reference Materials (as in NRC Regulatory Guide 4.15).
- Nuclear data was taken from NCRP Report No. 58, 1985.
- This source has a working life of 2 years.

Daniel James Van Dalsem
Quality Control

7-Aug-06
Date

IPL Ref. No.: 1198-84

ORTEC
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AN EG&G COMPANY
TELEPHONE (615) 482-4411 TELEX 55-7450

QUALITY ASSURANCE DATA

Semiconductor Radiation Detectors

WARRANTY BASIS

Shipment Date 10-11-76 Serial No. 16-1790

Model No. BA-024-300-500

Active Area (nominal) 300 mm²

Alpha Resolution 24 Kev FWHM(a)

Noise width 19 Kev FWHM(b)

Sensitive Depth (minimum) 500 microns

Operating Bias 300 volts

Pos ☒ Neg ☐

ACTUAL MEASUREMENTS

Alpha Resolution 20.3 Kev FWHM(a)

Noise width 16.0 Kev FWHM(b)

Reverse Current 0.95 μamps @ 250 volts

Temperature 23 °C

Sensitive Thickness ≥ 500 microns

Nominal Resistivity 6500 Ωcm.

Electrode Thickness: Au 40.3 μgm/cm²

Al 40.0 μgm/cm²

NOTES:

WARRANTY TERMS

Detectors are guaranteed to meet the minimum specifications of the warranty basis data above for a period of 12MO from the date of shipment if used in careful laboratory conditions as outlined in the ORTEC Detector Instruction Manual. During the term of the original warranty period the detector will be repaired or replaced at ORTEC option, at no charge to the user with service credit extended for unused portion of warranty period from date of notification of failure.

ORTEC makes no other warranties, express or implied, and specifically NO WARRANTY OF MERCHANTIBILITY OR FITNESS FOR A PARTICULAR PURPOSE.

ORTEC's exclusive liability is limited to repairing or replacing, at ORTEC's option, items found by ORTEC to be defective in workmanship or materials within one year from the date of delivery. ORTEC's liability on any claim of any kind, including negligence, loss or damages arising out of, connected with, or from the performance or breach thereof, or from the manufacture, sale, delivery, resale, repair, or use of any item or services covered by this agreement or purchase order, shall in no case exceed the price allocable to the item or service furnished or any part thereof that gives rise to the claim. In no event shall ORTEC be liable for special or consequential damages.

GENERAL SPECIFICATIONS

1. All detectors are operated in excess of 12 hours in vacuum of 10^{-6}mm of Hg before taking data shown.

2. Surface barrier type detectors have a front surface dead layer no greater than that corresponding to 20 Kev energy loss from a 5.5 Mev alpha.

a. Alpha resolution is the full-width at half-maximum (FWHM) of a 5.5 Mev thin Am^{241} alpha source spectrum line, measured with detector and source in vacuum, with stated high voltage, and includes the noise contribution of an ORTEC Amplifier System.

b. Noise Width is the FWHM of an ORTEC precision pulse generator line spectrum with detector connected as a noise source to input of an ORTEC Amplifier System, and at stated bias voltage. Noise width is generally somewhat less than alpha resolution, and is very nearly equal to beta or proton resolution for totally absorbed particles.

Data Certified by Reba E Hiatt

Special Test Data